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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

AN ESTIMATION OF THE FLYING QUALITIES OF THE KAISER FLEETWING ALL-WING AIRPLANE FROM TESTS OF A 1/7-SCALE MODEL

TED NO. NACA 2340

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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AN ESTIMATION OF THE FLYING QUALITIES OF THE KAISER FLEETWING ALL-WING AIRPLANE FROM TESTS OF A 1/7-SCALE MODEL

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By Gerald W. Brewer

SUMMARY

An investigation of a 1/7-scale powered model of the Kaiser Fleetwing all-wing airplane was made in the Langley full-scale tunnel to provide data for an estimation of the flying qualities of the airplane. The analysis of the stability and control characteristics of the airplane has been made as closely as possible in accordance with the requirements of the Bureau of Aeronautics, Navy Department's specifications, and a summary of the more significant conclusions is presented as follows.

With the normal center of gravity located at 20 percent of the mean aerodynamic chord, the airplane will have adequate static longitudinal stability, elevator fixed, for all flight conditions except for low-power operation at low speeds where the stability will be about neutral. There will not be sufficient down-elevator deflection available for trim above speeds of about 130 miles per hour. It is probable that the reduction in the up-elevator deflections required for trim will be accompanied by reduced elevator hinge moments for low-power operation at low flight speeds.

The static directional stability for this airplane will be low for all rudder-fixed or rudder-free flight conditions. The maximum rudder deflection of 30° will trim only about 15° yaw for most flight conditions and only 10° yaw for the condition with low power at low speeds.

Also, at low powers and low speeds, it is estimated that the rudders will not trim the total adverse yaw resulting from an abrupt aileron roll using maximum aileron deflection. The airplane will meet the requirements for stability and control for asymmetric power operation with one outboard engine inoperative. The airplane would

have no tendency for directional divergence but would probably be spirally unstable, with rudders fixed.

The static lateral stability of the airplane will probably be about neutral for the high-speed flight conditions and will be only slightly increased for the low-power operation in low-speed flight. The airplane will not roll against the ailerons in a side-slip maneuver. Although the airplane would probably meet the minimum requirements of $pb/2V$ of 0.07 at all speeds, there will be a loss in rolling ability of the airplane at high aileron deflections and at low flight speeds.

It is estimated that the wing stall will be a gradual movement forward from the trailing edge and will be accompanied by no sudden pitching or rolling accelerations. Some stall warning may be indicated by reduction in the elevator and aileron force gradients and by the shaking of the controls caused by unsteady flow over the surfaces near the stall.

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, tests have been made in the Langley full-scale tunnel to determine the aerodynamic characteristics of a 1/7-scale powered model of the Kaiser all-wing airplane. The results of these tests are presented in reference 1. Particular emphasis was given to the stability and control tests of the model in order to provide the data necessary for the evaluation of the flying qualities of this all-wing airplane design. The flying-qualities analysis presented in this report is based on the Bureau of Aeronautics, Navy Department's specifications for stability and control characteristics of airplanes. (See reference 2.)

Basis for Analysis

Inasmuch as this flying-qualities analysis is based on the test results of a 1/7-scale model, some of the more significant design features of the proposed airplane, not incorporated on the model, are discussed briefly. The model was not equipped with landing gear, nacelle ducting, or cowl flaps. The control surfaces were unsealed and were not equipped with trimming devices. With these limitations, the estimated stability and control characteristics as presented, would not be duplicated exactly by the full-scale airplane. In addition, the analysis is somewhat limited

in scope because of the absence of ground-board tests, the lack of control-system linkage information, and because the power conditions tested do not conform exactly to the specified flight conditions in reference 2. The general flight characteristics are presented, however, and the analysis provides a basis for the design of this type of airplane. As an aid to rapid cross reference of the material, reference to specific requirements is given by the same system of nomenclature used in the Bureau of Aeronautics, Navy Department's specifications.

A complete description of the model is presented in reference 1 but, for convenience, a three-view drawing of the model is given in figure 1 and the more significant geometric and physical characteristics of the airplane are presented in table I. Photographs of the model mounted for tests are given in figure 2.

The relation between the flight effective thrust coefficient (for a single propeller) and the lift coefficient simulated in the model tests is presented in figure 3 for sea-level operation. The range of power conditions tested included operation with windmilling propellers, normal-rated power, and military-rated power. A comparison of the flight torque coefficient for normal and military rated power with that for the model propeller is also presented in figure 3.

The pitching, rolling, and yawing moments are computed about a center of gravity located at 20 percent mean aerodynamic chord and on the airplane center line in the plane of the thrust axes. The data are referred to the stability axes which are defined as a system of axes having their origin at the center of gravity. The Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

COEFFICIENTS AND SYMBOLS

C_L	lift coefficient (Lift/qS)
C_m	pitching-moment coefficient (Pitching moment/qSc)
C_n	yawing-moment coefficient (Yawing moment/qSb)
C_l	rolling-moment coefficient (Rolling moment/qSb)
C_Y	lateral-force coefficient (Lateral force/qS)

[redacted]

C_h	hinge-moment coefficient (Hinge moment/$q\bar{b}\bar{c}^2$)
T_c'	effective thrust coefficient (T_e/qS)
Q_c	propeller torque coefficient ($Q/\rho V^2 D^3$)
$pb/2V$	helix angle, radians
C_{h_α}	rate of change of hinge-moment coefficient with angle of attack
C_{h_δ}	rate of change of hinge-moment coefficient with control-surface deflection
C_{n_ψ}	rate of change of yawing-moment coefficient with angle of yaw
C_{l_ψ}	rate of change of rolling-moment coefficient with angle of yaw
C_{Y_β}	rate of change of lateral-force coefficient with angle of sideslip
T_e	effective thrust of one propeller
Q	propeller torque
S	wing area
c, M.A.C.	mean aerodynamic chord
b	span
$\bar{c}$	root-mean-square chord
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$
ρ	mass density of air
V	free-stream velocity
D	propeller diameter
p	angular velocity in roll, radians per second
r	angular velocity in yaw, radians per second
t	time, seconds

[redacted]

α	angle of attack of the thrust axis, degrees, relative to the free-stream direction
ψ	angle of yaw, degrees, positive with left wing forward
β	angle of sideslip, degrees ($\beta = -\psi$)
ϕ	angle of bank, degrees, positive with right wing lowered
δ	control-surface deflection, degrees, positive with deflection downward or to the left

Subscripts:

a	aileron
e	elevator
r	rudder
L	left
R	right
T	total

Ratio of radius of gyration to wing span:

K_X/b	0.21
K_Y/b	0.11
K_Z/b	0.21

DISCUSSION

Longitudinal Stability and Control

D-1. Dynamic longitudinal stability.- The dynamic stability characteristics of the airplane, with elevator free, are not estimated because of lack of suitable data. The short-period dynamic oscillation, with elevator fixed, has been computed; however, for the windmilling propeller condition by the methods employed in reference 3. It is indicated from this analysis that this oscillation will probably be very heavily damped at all speeds because

an initial disturbance will be damped to one-half its original amplitude in about one-tenth of an oscillation.

There is no requirement specified for the long period of phugoid oscillation involving changes in speed, but a brief analysis, using procedures in reference 3, indicated that for the condition of windmilling propellers at low speed ($V \approx 100$ mph) the motion would be one of increasing oscillation. The damping in pitch for this all-wing airplane is low, which results in a short period of the phugoid oscillation (16 sec) accompanying the unstable motion. The increasing oscillations also occur for flight at high speed ($V \approx 200$ mph) but the period of oscillation is much longer, and should not give any difficulty in the control of the airplane.

D-2. Static longitudinal stability.- The stick-fixed neutral point variations with lift coefficient for the range of propeller operation from propellers windmilling to military-rated power are presented in figure 4. The neutral point location for normal-rated power is about 35 percent mean aerodynamic chord over the speed range from 170 to 98 miles per hour ($C_L = 0.3$ to 0.9) which is 15 percent mean aerodynamic chord aft of the normal center-of-gravity position. There is a further rearward movement of the neutral point to about 41 percent mean aerodynamic chord upon applying military-rated power at any speed. The most critical condition of static longitudinal stability will occur for low-power operation at low speeds. For this condition the neutral point moves forward rapidly as the speed is decreased so that at a speed near the landing speed the airplane would be neutrally stable, longitudinally. The cause for this unstable trend was found to be directly related to the air-flow phenomenon over the wing. (See reference 1.) Separation occurred at the wing trailing edge and progressed forward steadily with increased lift coefficient. Application of power, however, eliminated separation at the center section.

All data obtained are representative of only the tab-neutral condition and for this reason sufficient data are not available for a complete determination of the control-free neutral points. An indication of the control-free static stability, however, is given by the variation with speed of pitching-moment coefficient, for $C_{h_e} = 0$, in figure 5. At the trim points shown, the stable slopes of the pitching-moment curves indicate that for the normal center-of-gravity location of 20 percent mean aerodynamic chord, the airplane will be longitudinally stable, elevator free, for each power condition investigated.

[redacted]

D-3. Elevator control power.- D-3.1 - The variations of elevator deflection for trim with airspeed (fig. 6) show that the elevator, with maximum downward travel of 10°, is sufficient only to trim the airplane up to speeds of about 130 miles per hour. The curves extending beyond this speed were obtained from extrapolation of the test data of reference 1, by assuming that for a moderate range of deflections beyond 10° that the effectiveness of the elevator would be essentially unchanged. These results indicate that revisions to the elevator design are necessary, such as increasing the area or deflection range, in order to secure adequate control throughout the speed range. The trim curve for the windmilling propeller condition shows a very sudden decrease in the rate of up-elevator deflection as the speeds decrease below 100 miles per hour. This decrease in the rate of elevator deflection required for trim at low speeds is associated with the low degree of static longitudinal stability for this condition which has been discussed previously.

D-3.2 - By the use of the elevator control alone, it will be possible to develop the limit load factor or the maximum lift coefficient at any speed. Computations made for the most critical condition, consisting of a pull-up to the maximum lift coefficient from high speed, indicate that an increment of about 15° of up-elevator deflection will be required to develop the limit load factor of 2.67 at maximum lift.

The remaining requirements in this section relating to the landing and take-off conditions are not discussed because of the absence of ground-board test data and lack of information pertaining to the design of the airplane.

D-4. Elevator control forces.- The elevator hinge moments associated with the trim elevator deflections discussed in the previous section are presented in figure 7. Although stick forces are not presented, the hinge moments give an estimate of the handling qualities and in addition will be useful in the determination of a suitable control system. The airplane will have a stable stick-force variation with speed because from a given trim speed, push forces are required to increase the speed and pull forces are required to reduce the speed. It is noted, however, that the rate of change of hinge moment with speed is large, and the large moments developed for only moderate speed changes from a trim point will require application of servo-control or a power-boost system to produce control forces within acceptable limits.

The curve for the windmilling propeller condition at low speeds shows a considerable reduction in hinge moment as the speed

decreases below 100 miles per hour. This reduction in hinge moments is associated with the trailing-edge separation that occurs at the low speeds with low powers.

D-4.1 - The test results of reference 1 indicate that in steady turning flight the changes in normal acceleration would be about proportional to the change in stick force inasmuch as the curves of pitching moment against elevator deflection and curves of elevator hinge moment for trim against elevator deflection are all smooth and essentially straight-line variations.

Directional Stability and Control

E-1. Dynamic directional stability.- E-1.1 - The dynamic directional stability characteristics of the airplane controls fixed were estimated by the methods given in reference 4 and the results of the calculations showing the boundaries for spiral and directional divergence are presented in figure 8. For illustration, two points are shown on the figure which are values of C_{n_ψ} and C_{l_ψ} obtained from the test results of the model (reference 1) for high-speed and low-speed flight at a low-constant thrust condition. The region in which there would be no tendency for either spiral or directional divergence is small and it is evident from the relative location of the values for the two speed conditions investigated that with respect to the boundaries, the airplane will most likely be spirally unstable, but will have no tendency for directional divergence. The spiral divergence, however, will probably not introduce any difficulty in flight.

E-2. Static directional stability.- E-2.1 - The characteristics of the airplane in a sideslip are obtained from a summary of model test results given in figure 9. The variations of rudder deflection for trim, and the rudder hinge moments with angle of yaw indicate that the airplane will possess rudder-fixed static stability, although in some cases the degree of stability is low. The average values for the static stability parameter C_{n_ψ} were found in reference 1 to be about -0.0004 per degree. For all angles of attack and power conditions investigated, right rudder deflection produces a steady sideslip to the left, and vice versa. The rudder deflections for trim are substantially porportional to the angle of steady sideslip for all conditions. The proportionality of the trim rudder deflection with sideslip, however, is about one-half to one-third of that generally desired.

[redacted]

E-2.2 - The rudder-fixed static directional stability appears sufficient to control the sideslip resulting from sudden application of the aileron in a rolling maneuver out of a turn with the rudder fixed. For the condition with the least degree of directional stability (windmilling porpellers) the requirement would be satisfactorily met inasmuch as about 0.75° of sideslip would be developed per 5 percent of full aileron deflection. This value will be a conservative estimate because the directional stability will be somewhat greater for the higher power condition actually specified for this maneuver.

E-2.3 - The airplane will be statically stable, directionally with the rudders free for all flight conditions inasmuch as the yawing-moment coefficient curves, for $C_{h_r} = 0$, in figure 10 show stable, although low, slopes. Rudder-free static stability is also shown by the stable slopes of the hinge-moment curves in figure 9. The rudder hinge moments are nearly proportional to the angle of sideslip and, furthermore, there is no tendency for rudder overbalance in the sideslip range investigated (10° to -15°).

E-2.4 - The rudder-free static directional stability for the airplane operating with the right outboard engine inoperative will be sufficient to maintain straight flight by banking and sideslipping with the rudder free. The rudder-free characteristics of the model (fig. 10) show that this mode of asymmetric power reduced the normal power yawing moment at a given angle of sideslip and, consequently, reduced the sideslip angle for trim. However, computations show that the more critical type of asymmetric power operation will be with the left outboard propeller inoperative and with the remaining engines developing rated power. These computations neglect the small changes in sidewash that may occur at the tail but do include the small additional moment caused by the side force on the yawed propeller. The major change in yawing moment due to asymmetric power operation was contributed by the unbalanced thrust forces of the propellers. A comparison of the experimental and estimated asymmetric power conditions with the normal rated power operation (fig. 11) shows that the airplane will trim at a sideslip angle to the right of the order of 12° with the rudder free and with the left outboard propeller inoperative. With the assumption that the lateral force characteristics will not be substantially affected by the change in condition of asymmetric power, it is estimated that the angle of bank accompanying this sideslip angle will be about 4°. This illustrative example is given for a lift coefficient of about 1.0 ($V \approx 93$ mph) where the power effects are large. Inasmuch as the flight condition specified is that for maximum range, the results as presented will therefore represent a most severe condition for rudder-free trim.

[redacted]

E-3. Rudder control power.- E-3.1 - The results of the rudder tests at zero yaw reported in reference 1 are summarized in figure 12 by the variations with airspeed of the rudder deflections and hinge moments required for directional trim. A deflection range from about 5° left to10° right will provide trim at the low speeds and at all power conditions. At high speeds this deflection range is substantially reduced. Of these trim rudder deflections, however, only the windmilling propeller and asymmetric power satisfy the requirement of having the wings level. For the two higher power conditions there is an accompanying untrimmed bank angle although the greatest angle reached would be only about 2.5°. The most difficult condition for maintaining wing-level flight would be at the high angles of attack with high power operation and for this condition sideslip angles as great as 15° will be reached.

The effectiveness of the rudder in trimming out the airplane yawing moment in a sideslip has been shown previously to be rather low. Figure 9 shows that for only the high power operation can 15° of sideslip be held by the maximum rudder deflection of 30° and that at high angles of attack with low power the limiting sideslip angle is only about 10°.

E-3.2 - The directional stability and the rudder effectiveness have been shown to be very low for low-speed flight with the propellers windmilling. It is estimated that at the landing condition the rudders would not be capable of maintaining directional control in a 90° crosswind of velocity 20 percent of the stalling speed. Adequate control at the instant of take-off for this same crosswind condition would be possible because propeller operation at take-off power considerably increases the effectiveness of the rudder for trim.

E-3.4 - The test results show that for the asymmetric power condition tested (right outboard propellor windmilling and remaining engines operating at rated power) very small rudder deflections would be required to hold zero sideslip at all speeds. (See fig. 9(d).) It has been shown, however, that the most critical asymmetric power configuration with one engine inoperative consists of the left rather than the right outboard propeller windmilling. The estimated trim curves for this condition are given in figure 13 together with the curves for the asymmetric power condition tested (from fig. 9(d)). A large rudder deflection of about 17° will be required for directional trim at a low flight speed. It is important to note that, at speeds near the landing speed, the airplane with the left engine inoperative cannot be trimmed directionally in straight flight for yaw angles to the right greater than 8° with full-right rudder deflection.

[redacted]

E-3.5 - The adverse aileron yaw is found to be negligible (reference 1) for the moderate aileron deflections that would be encountered for lateral control at medium and high speeds. The rudder control would be adequate for such conditions. At low speeds, or high angles of attack, however, maximum aileron deflection produces an adverse yawing-moment coefficient of the order of 0.0035. Although this value is not particularly large in itself, the estimations of the yawing moment of the airplane in a roll (from reference 5) indicate that a substantial increment of yaw due to roll must be included with the adverse aileron yaw. At the lower speeds, it is estimated that for low-power operation only about one-half the total adverse yaw can be controlled by full-rudder deflection. Smaller rudder deflections will be required if the rolling maneuver is accomplished during rated-power operation.

E-4. Rudder pedal forces.- The necessary information for converting the rudder hinge moments to rudder pedal forces are not available and therefore no prediction of limiting control forces has been made. The hinge-moment variations with speed, at zero yaw (fig. 13) and in yaw (fig. 9) are very useful nevertheless in estimating the flying qualities. The variations of rudder hinge moment for trim with angle of yaw have been shown to be smooth curves that increase steadily with increases in angle of yaw. There is also no indication of a tendency for rudder lock through 15° of yaw. Because of the exceptionally large control surfaces, however, the rudder hinge moments become very large for high rudder deflections even at low flight speeds and moderate angles of yaw. It is evident, from the magnitude of these rudder hinge moments for some flight conditions that moment reduction ratios as much as 20:1 must be effected at the cockpit in order to insure pedal forces within acceptable limits.

Lateral Stability and Control

F-2. Static lateral stability.- F-2.1 - The static lateral stability characteristics of the airplane with ailerons fixed, are shown in figure 14 by the variation of aileron deflection for lateral trim with angle of sideslip for a range of angle of attack and power conditions. There is a deflection ratio of 3:1 between the left and right ailerons, and although the results show the left aileron deflections only, the effect of deflection of the right aileron has been considered. The results are not given for the sideslip angle of -15° because the rudders are not capable of trimming the airplane directionally at that attitude. There is about neutral static lateral stability for the high-power operation at the lower angles of attack. There is a low degree of static lateral stability shown for the windmilling propeller operation at the higher angle of attack. Because of the absence of aileron hinge-moment data, the aileron-free stability can not be estimated.

[redacted]

F-2.2 - For all the power conditions and angles of attack investigated in reference 1 and for the conditions shown in figure 14 the variation of rolling-moment coefficient with angle of sideslip are stable, or neutrally stable. The effective dihedral angle corresponding to these slopes vary from zero to about 1.5°. For no condition would the rolling moment due to sideslip be so great as to cause a reversal in rolling velocity resulting from aileron yaw in a rolling maneuver.

F-2.3 - The test results show that stable but low variation of lateral-force coefficient with angle of yaw exists for most flight conditions. The values for $C_{Y_{\beta_{trim}}}$ of figure 9 vary from about 0 to -0.0020 per degree for the range of power conditions and angles of attack tested. With the propellers windmilling, it would not be possible to bank the airplane and for any other flight condition the angle of bank developed would be small.

F-3. Aileron control power.- F-3.1 - The characteristics of the airplane in an aileron roll have been estimated in accordance with the methods presented in reference 6. The results given in figure 15 show time histories of the rolling and yawing velocities, angle of sideslip, and angle of bank resulting from an abrupt deflection of the ailerons at two flight speeds. The variation of rolling acceleration with time following an abrupt control deflection is in the correct direction for stable control because the initial slope of the rolling-velocity curve is positive and the curve shows no tendency toward a time lag.

F-3.2 - The rolling velocity curves show the most rapid rise in velocity within 1/2 second from the initial movement of the ailerons, and the resulting peak rolling acceleration would occur within the maximum allowable time lapse. It is of interest to note, for comparison with values for conventional airplanes, that the maximum rolling velocity is only 4° per second at a speed of 90 miles per hour and is about 13° per second at 169 miles per hour.

The remaining information in figure 15 shows a low rate of yawing velocity and a considerable time lag before the sideslip angle in an aileron roll becomes appreciable. For the two speeds computed, as much as 3.5 to 4 seconds elapse before a sideslip angle of 10° is reached.

F-3.3 - The variation of rolling velocity with aileron deflection for various speeds can be illustrated by the helix-angle curves of figure 16. Smooth and nearly proportional variations of rolling velocity with deflection occur for the higher speeds

[redacted]

although there is some reduction in slope of the curve above half-aileron deflection which becomes more pronounced with decreases in speed. For the speeds below 100 miles per hour, however, there is a sharp break in the helix-angle curve near half-aileron deflection, followed by a loss in rolling effectiveness at higher deflections.

F-3.4 - The values of the wing-tip helix angle shown in figure 16 were calculated from the relation $\Delta C_l/C_{l_p}$ where ΔC_l is the total increment in rolling-moment coefficient at a given deflection of the ailerons and C_{l_p} is the coefficient of damping in roll (0.483) obtained from reference 7. No corrections have been applied to these values of $pb/2V$ for the effects of wing twist and aileron distortion at high speed and for the effect of roll due to sideslip at low speeds. It is shown that values for $pb/2V$ of 0.07 or greater can be attained at all speeds within the available deflection range. As discussed in the previous section, the most critical condition of lateral control would occur at speeds near the landing and at large aileron deflections. It was observed in the tests of the model that this loss in lateral control was caused by stall in the region of the ailerons.

F-3.5 - Although the lateral handling characteristics may be considered unsatisfactory for the landing condition with use of large aileron deflections, a more exact evaluation of the rolling characteristics indicates that the minimum rolling requirements can be satisfied. The tip velocity due to rolling for a $pb/2V$ value of 0.07 will be greater than the present requirement of 10 feet per second for the lowest speed condition of 90 miles per hour.

F-3.6 - The rolling-moment increments due to asymmetric power are sufficiently low so that the ailerons are capable of producing adequate lateral control when the airplane is operated with the asymmetric power conditions described in the section on directional control.

F-4. Aileron forces.- F-4.1 - The aileron control-force characteristics with the airplane in a steady sideslip are not presented because of insufficient aileron hinge-moment data with the model yawed. The aileron hinge moments accompanying the helix-angle variations discussed in the previous section are given in figure 16. In general, for speeds greater than 103 miles per hour, the aileron hinge moments increase steadily with increased aileron deflection. At lower speeds, however, a loss in control-feel

is indicated by the low slope of the hinge-moment curves up to about half-aileron deflection. The ailerons will develop very large control forces which will become unmanageable for rolling maneuvers and for lateral trim even at moderate angles of sideslip.

In general, there was a wide range of values of C_{h_β} and C_{h_α} for the control surfaces tested (reference 1) and in order to illustrate the range and magnitudes of these values the following table is included. The slopes of the curves were measured at zero surface deflection and at zero yaw.

Control surface	C_{h_β}			
	P.W.[1]		N.R.P.[2]	
	α = 6.0	α = 16.5	α = 3.3	α = 12.5
Elevator	-0.0059	-0.0070	-0.0107	-0.0186
Rudder	-0.0050	-0.0060	-0.0054	-0.0089
Aileron	-0.0096	-0.0059	-------	-------
Control surface	C_{h_α}			
	P.W.[1]		N.R.P.[2]	
	α = 6.0	α = 16.5	α = 3.3	α = 12.5
Elevator	-0.0030	-0.0025	-0.0030	0
Rudder	-0.0010	0	-0.0015	-0.0035
Aileron	-0.0070	-0.0157	-------	-------

[1]P.W. = Propellers windmilling.
[2]N.R.P. = Normal rated power.

It is apparent that values of C_{h_β} as high as those shown would be prohibitive for the airplane, and it is estimated that even with a value for C_{h_β} of about -0.002, obtainable by close aerodynamic balance and careful attention to the detail design, the

[redacted]

hinge moments would produce excessive control forces. It appears, therefore, that a mechanical booster will be necessary in the control system in order to obtain control forces within acceptable limits.

Stalling Characteristics

Some indication of the stalling characteristics of the airplane is given by the tuft studies on the 1/7-scale model. The test Reynolds number of 2,230,000 at stall is about one-tenth that at full scale; nevertheless, the general flow characteristics over the wing of the design configuration are considered represented by these tuft surveys. A detailed description of the air flow over the wing is given in reference 1, but the more important findings are summarized here as well.

With the propellers windmilling and at an angle of attack of 9° ($C_L \cong 0.7$) a strong inflow occurred along the trailing edge of the outer panels. At 13°, the first indication of separation appeared at the rear of the wing. The stall progressed steadily forward on the wing as the angle increased and at $\alpha = 19.5°$ the outer panels were essentially stalled. Except for some roughness over the elevator, the flow over the center section of the wing spanned by the vertical surfaces was relatively undisturbed. The lift coefficient curve showed a gradual loss in lift near the stall and no sharp loss in lift after stall. There was very little movement in the center of pressure near the stall because the pitching moments showed neither a strong nose-down nor nose-up pitching tendency at stall. Wing stall has a marked effect on the flow over the ailerons and, consequently, causes a reduction in the aileron effectiveness.

It would appear, then, from these results, that the airplane will experience a gradual stall progression and will not have any sudden angular velocity in pitch or excessive rolling motion. There will probably be a warning of stall, however, in the loss of feel of the elevator and aileron controls. Near the stall, the rate of change of elevator and aileron control forces with speed will be reduced and there will be experienced a reduction in the upward movement of the elevator. Due to the fluctuating nature of the separated air flow over the wing trailing edge, the elevator and ailerons may experience some buffeting prior to wing stall.

[redacted]

CONCLUSIONS

Tests of a 1/7-scale powered model of the Kaiser Fleetwing airplane have been conducted at the Langley full-scale tunnel. From the results of these tests, the flying qualities of the airplane have been estimated and the significant conclusions are presented as follows:

1. For rated-power operation the airplane will be longitudinally stable statically, at all speeds with center-of-gravity locations forward of about the 35-percent mean aerodynamic chord point. With propellers windmilling, there is a forward neutral point shift from 31 percent mean aerodynamic chord at a speed of 170 miles per hour ($C_L = 0.3$) to 20 percent mean aerodynamic chord at a speed of 93 miles per hour ($C_L = 1.0$). For low-power operation at low speeds, it appears that with the normal center of gravity at 20 percent mean aerodynamic chord, the airplane will have approximately neutral static longitudinal stability.

2. There is insufficient down-elevator deflection available to produce longitudinal trim beyond speeds of 130 miles per hour. Furthermore, at low flight speeds with low power, the decrease in longitudinal stability causes a sudden decrease in the rate of change of deflection against speed.

3. The airplane will be directionally stable, statically, rudders fixed or free, for all flight conditions investigated. The static stability parameter C_{n_ψ}, however, is rather low and averages about -0.00040 per degree for most conditions tested.

4. For most flight conditions, it appears that about 15° yaw would be the limit for directional trim with maximum (30°) rudder deflection. The rudders will not be sufficiently powerful to trim the total adverse yawing moment resulting from an abrupt aileron roll in low-power, low-speed flight.

5. With one engine inoperative, the most critical condition for directional control will be with the left outboard propeller windmilling and with the remaining three engines operating at full power. In low-speed flight (V = 93 mph) and for this power condition, it is estimated that the airplane can be trimmed, rudder free, by sideslipping about 12° and banking about 4°. For this low-speed condition, about 15° of rudder deflection will probably be required to maintain unyawed flight.

6. In the sideslip range of about ±10° the airplane will have approximately neutral static lateral stability for flight in the

high-speed range. The lateral stability is a little greater for the low-power, low-speed flight condition. The rolling moments developed in a sideslip will never be so large as to cause a reversal in rolling velocity in an aileron roll.

7. The airplane will probably have sufficient lateral control, even at low speeds. There is, however, a reduction in the rolling effectiveness above half-aileron deflection at the low flight speeds.

8. The hinge moments for all control surfaces are very large even for flight at low speeds and at moderate angles of yaw. In order to insure wheel and pedal forces within acceptable limits, a booster system, in addition to carefully balanced control surfaces will probably be required.

9. Airplane stall will be gradual and no sudden pitching and rolling will accompany the stall. Some stall warning may be indicated by a reduction in elevator and aileron forces and by fluctuations in these controls from the unsteady flow over the surfaces near the stall.

10. Estimates of the dynamic stability characteristics of the airplane with controls fixed indicate that:

(a) The short-period longitudinal oscillations will be heavily damped.

(b) The phugoid (long-period) oscillation will be divergent at low speeds.

(c) There will be no tendency toward directional divergence.

(d) Spiral divergence is likely to occur.

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National Advisory Committee for Aeronautics
Langley Field, Va.

Gerald W. Brewer
Gerald W. Brewer
Aeronautical Engineer

Approved: S. Katzoff, for
Clinton H. Dearborn
Chief of Full-Scale Research Division

ESY

[redacted]

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2. Anon.: Specification for Stability and Control Characteristics of Airplanes. SR-119A, Bur. Aero., April 7, 1945.

3. Zimmerman, Charles H.: An Analysis of Longitudinal Stability in Power-Off Flight with Charts for Use in Design. NACA Rep. No. 521, 1935.

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5. Pearson, Henry A., and Jones, Robert T.: Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist. NACA Rep. No. 635, 1938.

6. Wolowicz, Chester H.: Prediction of Motions of an Airplane Resulting from Abrupt Movement of Lateral or Directional Controls. NACA ARR No. L5E02, 1945.

7. Swanson, Robert S., and Priddy, E. LaVerne: Lifting-Surface-Theory Values of the Damping in Roll of the Parameter Used in Estimating Aileron Stick Forces. NACA MR No. L5E07, Bur. Aero., 1945.

[redacted]

TABLE I

PHYSICAL AND DIMENSIONAL CHARACTERISTICS OF THE KAISER FLEETWING ALL-WING AIRPLANE

Design gross weight, lb	175,000
Wing:	
Area, sq ft	7920
Span, ft	290
Mean aerodynamic chord, ft	27.3
Location aft of root chord leading edge, ft	1.74
Aspect ratio	10.6
Taper ratio	0.20
Root section, modified with trailing edge reflexed upward	NACA 63,4-020
Tip section, modified with trailing edge reflexed upward	NACA 65,3-018
Dihedral of outer panel, deg	1.7
Wing twist, deg	0
Sweepback of 20-percent chord line, deg	0
Wing loading, lb/sq ft	22.1
Aileron:	
Area aft of hinge line, each, sq ft	277
Aileron balance, percent	15.4
Span, ft	90
Root-mean-square chord, ft	3.24
Hinge line, percent of wing chord	85
Maximum deflection, deg	10, -30
Elevator:	
Area aft of hinge line, sq ft	193
Elevator balance, percent	12.7
Span, ft	48.2
Root-mean-square chord, ft	4
Hinge line, percent wing chord	90
Maximum deflections, deg	10, -30

[redacted]

TABLE I - Concluded

PHYSICAL AND DIMENSIONAL CHARACTERISTICS - Concluded

Vertical surface:	
Total area, sq ft	820
Rudder area aft of hinge line, total, sq ft	267
Rudder balance, percent	12.5
Vertical tail height above wing trailing edge, ft	19.82
Root-mean-square rudder chord, ft	3.02
Hinge line, percent of fin chord	70
Maximum deflection, deg	±30
Propeller:	
Designation	Hamilton Standard 6491A-0
Diameter, ft	15.167
Number of blades	4
Propeller gear ratio	0.45

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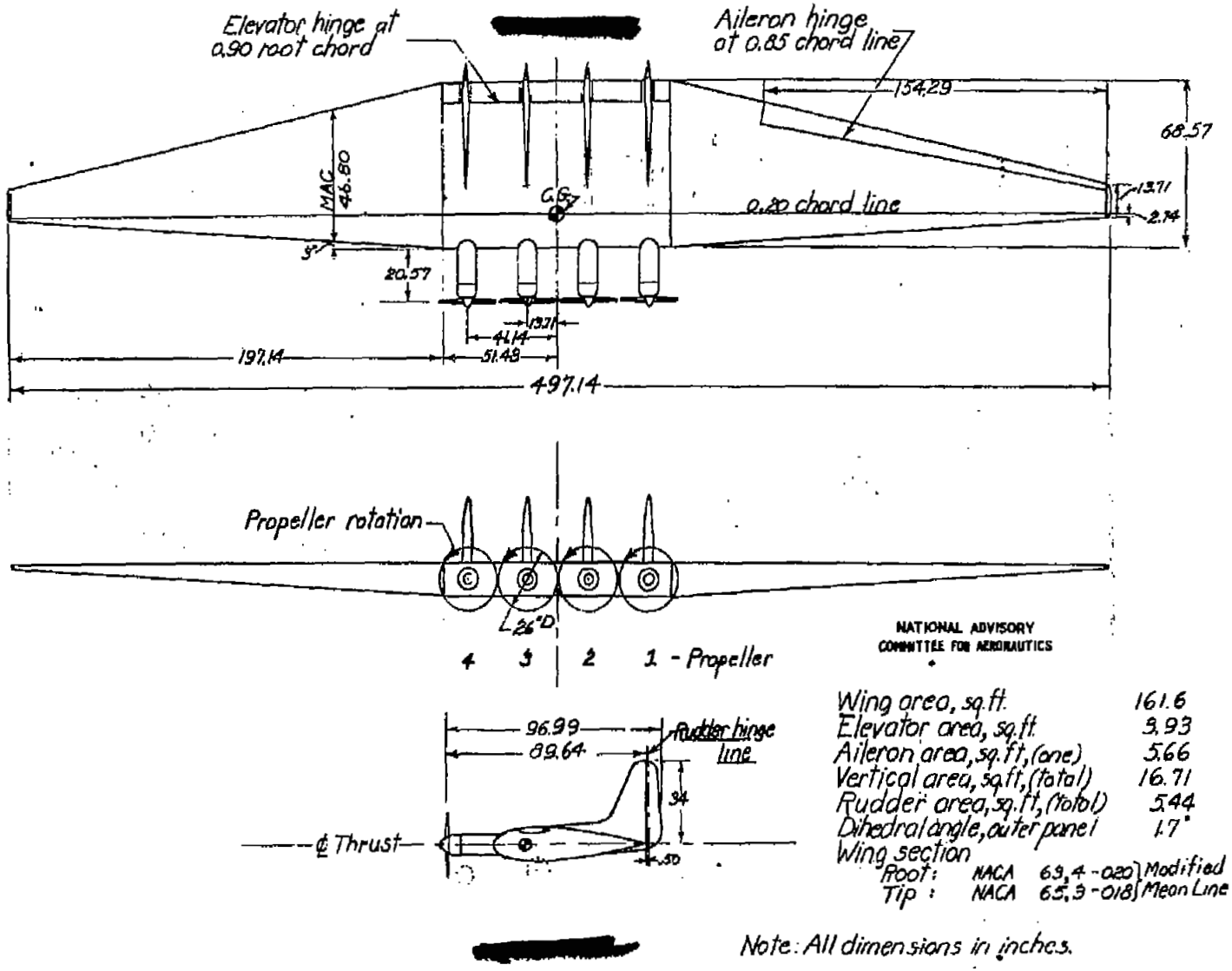
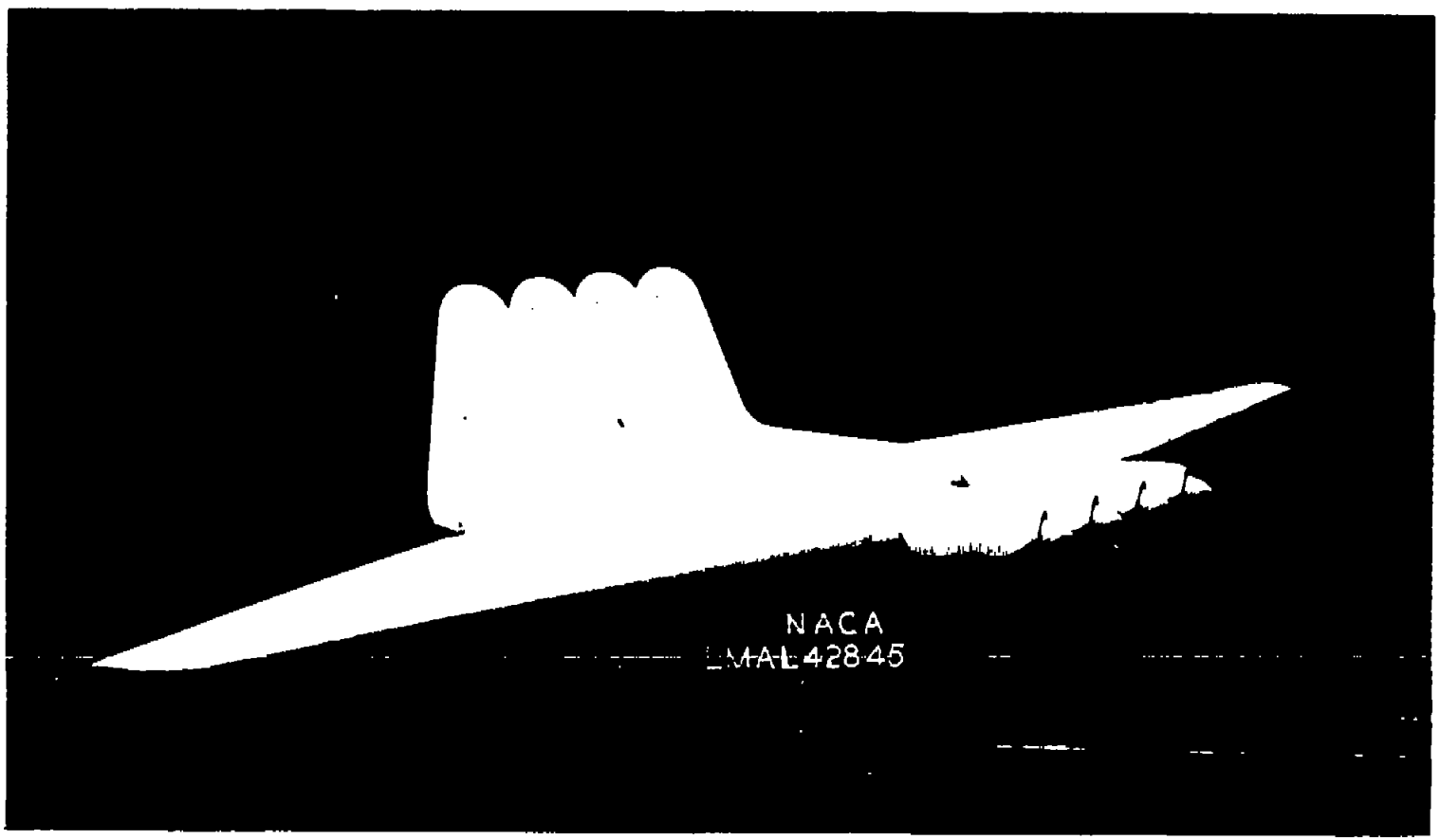


Figure 1.- Three-view drawing of the 1/7-scale model of the Kaiser Fleetwing all-wing airplane.



(a) Three-quarter front view.

Figure 2.- The 1/7-scale model of the Kaiser Fleetwing all-wing airplane mounted for tests in the Langley full-scale tunnel.

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(b) Three-quarter rear view.

Figure 2.- Continued.

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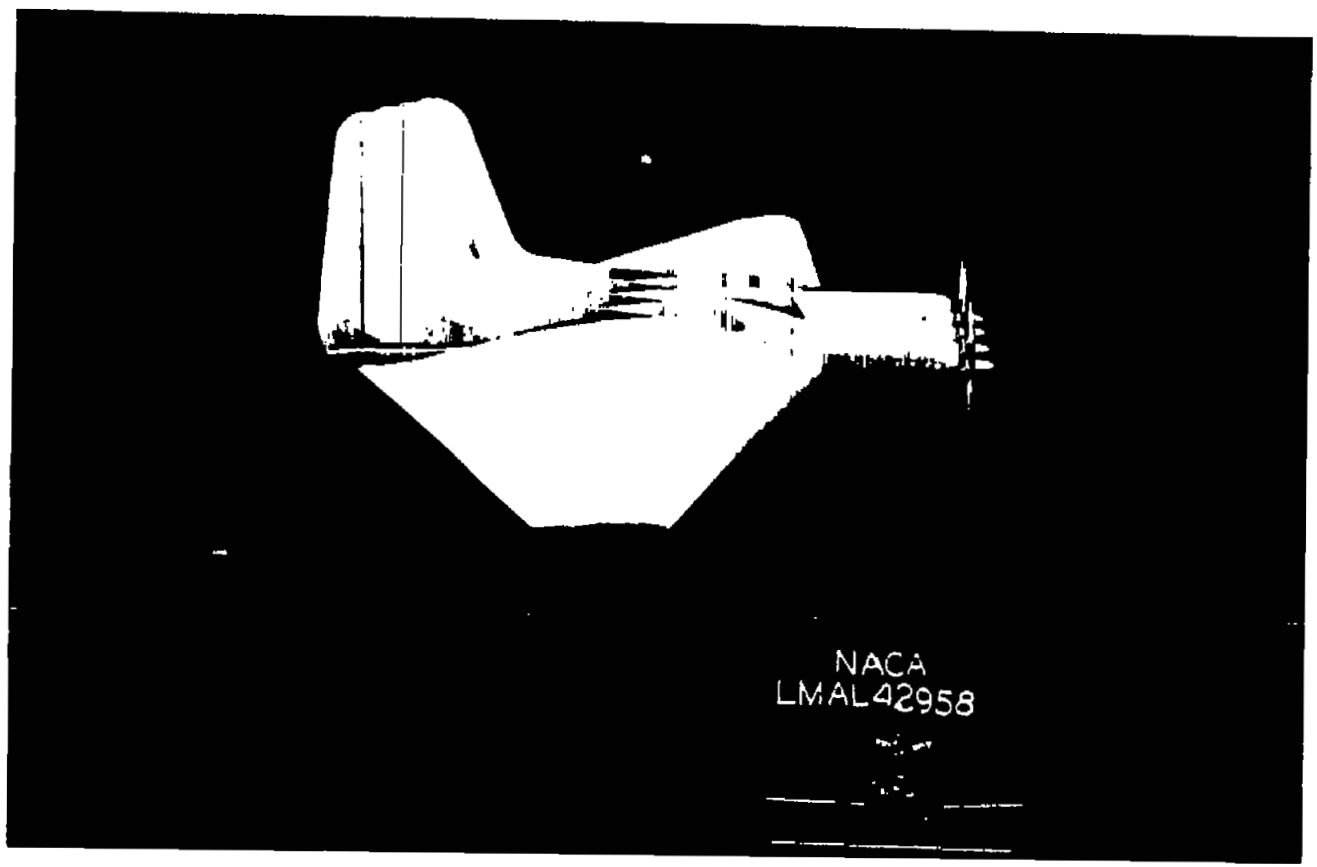

(c) Side view.

Figure 2.- Concluded.

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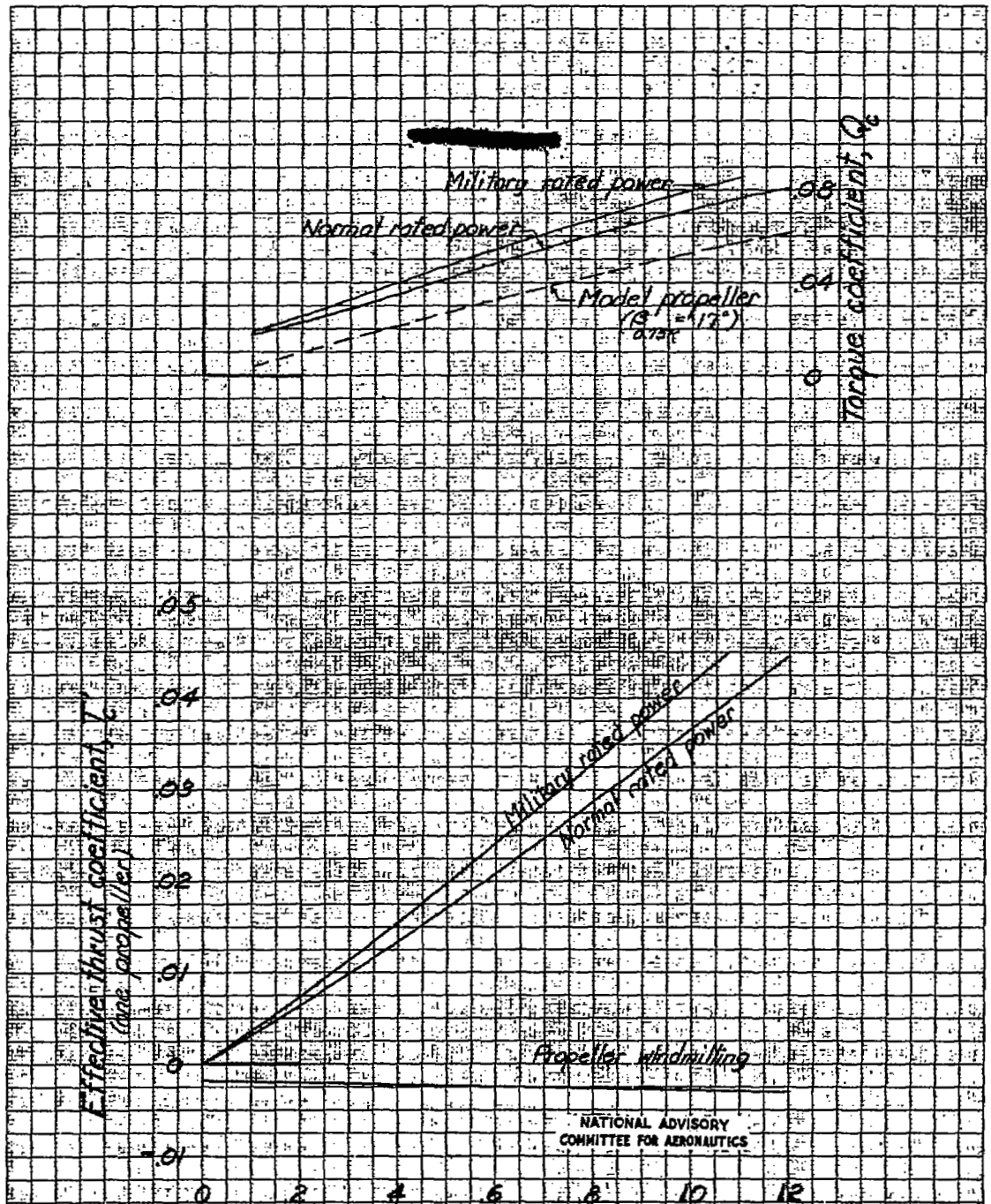


Figure 3.- Variation of effective thrust coefficient and torque coefficient with lift coefficient for a single propeller. Sea-level operation; $\frac{W}{S}$ = 22.1 pounds per square foot.

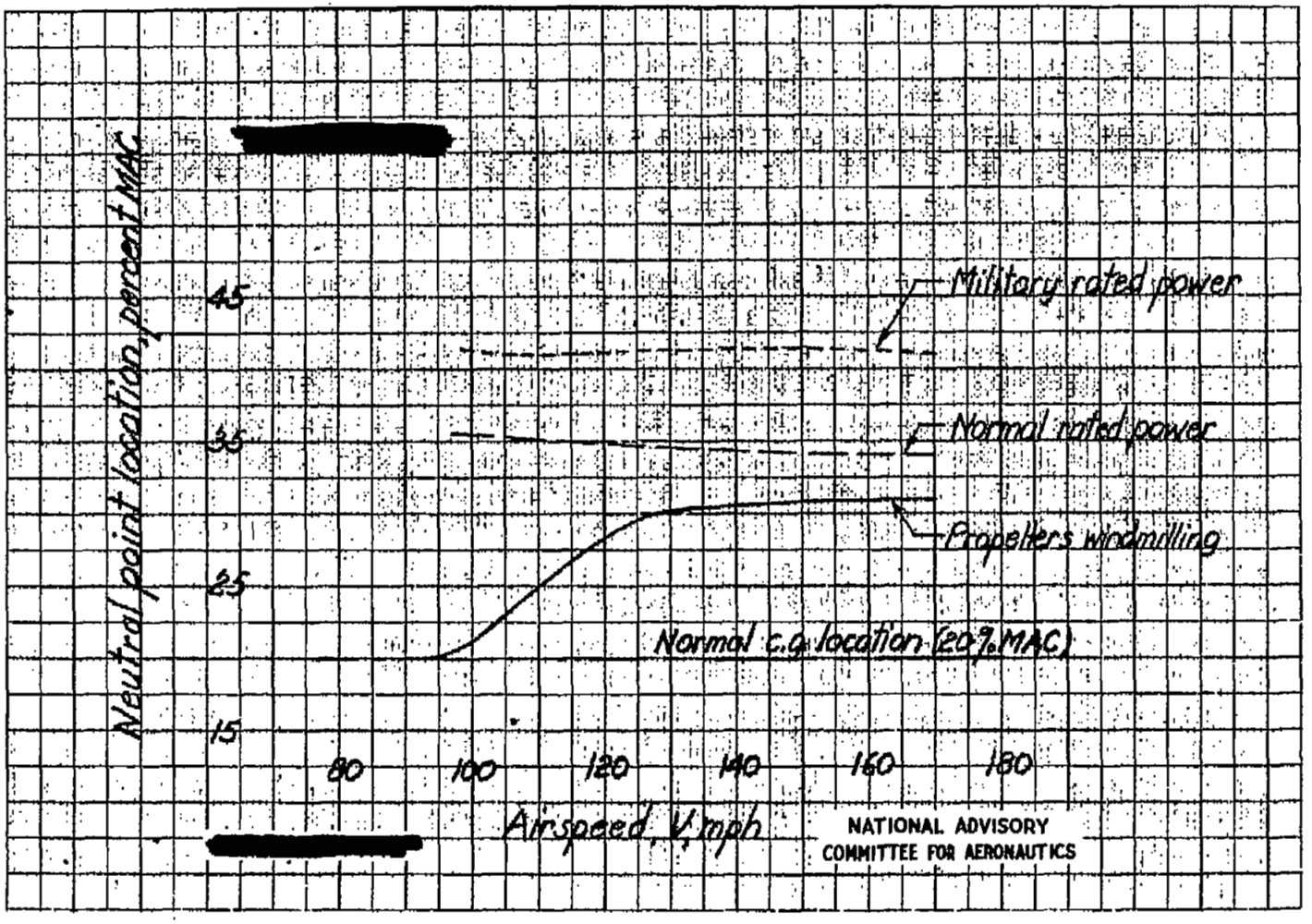


Figure 4.- Variation of neutral point location with airspeed for sea-level operation. Elevator fixed.

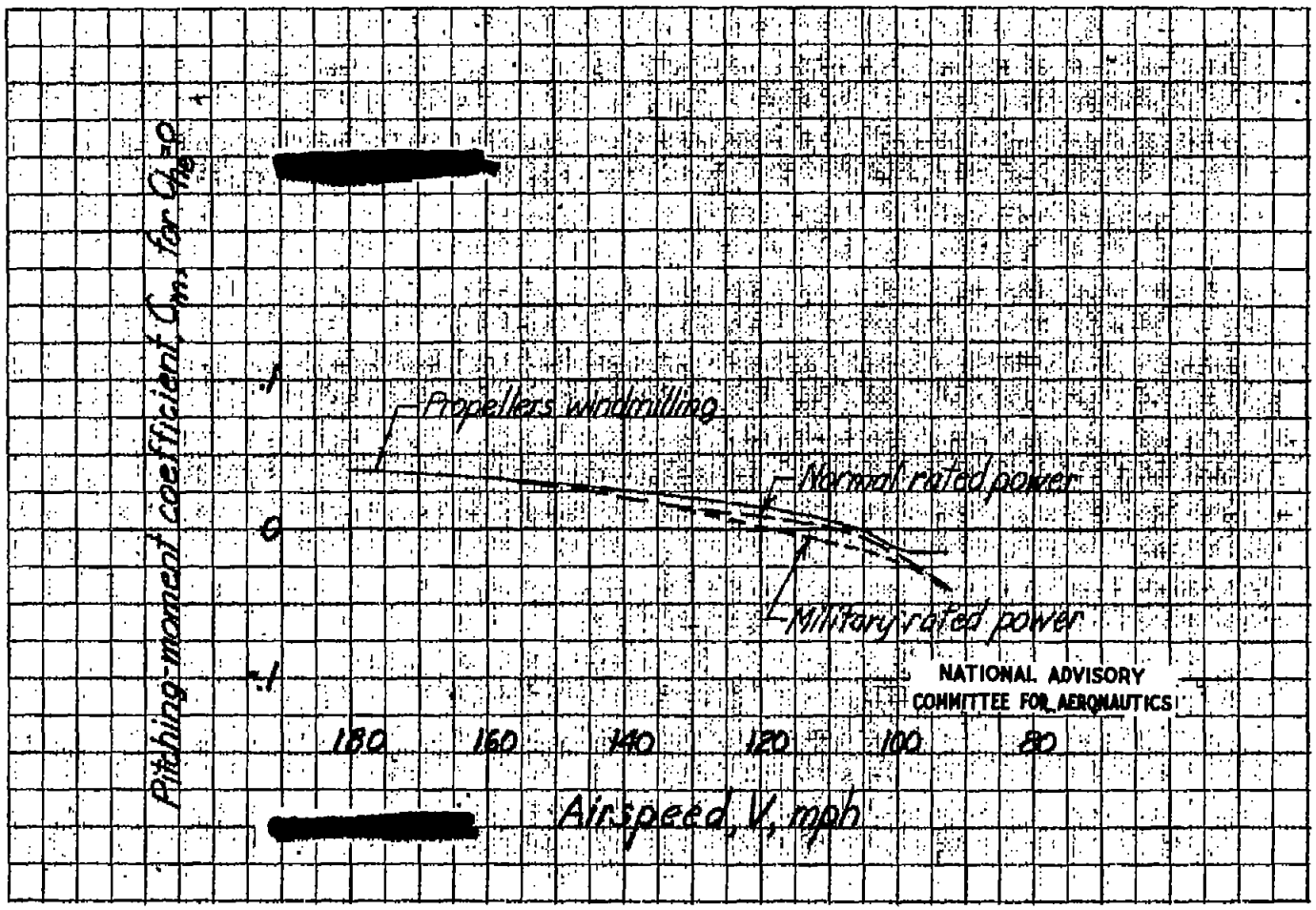


Figure 5.- Variation of elevator-free pitching-moment coefficient with airspeed. Sea-level.

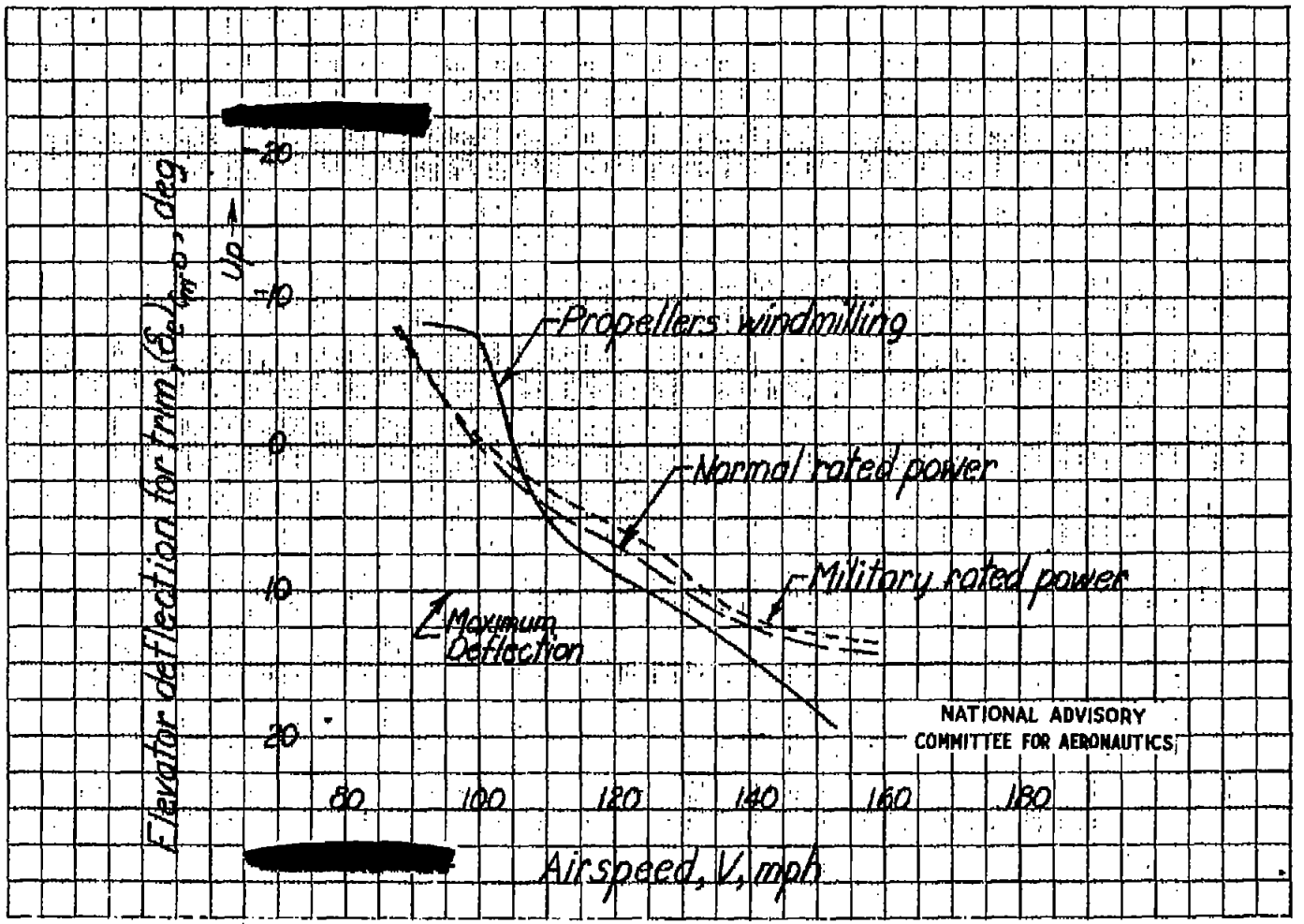


Figure 6.- Variation of elevator deflection for trim with airspeed. Sea-level operation; tab neutral configuration.

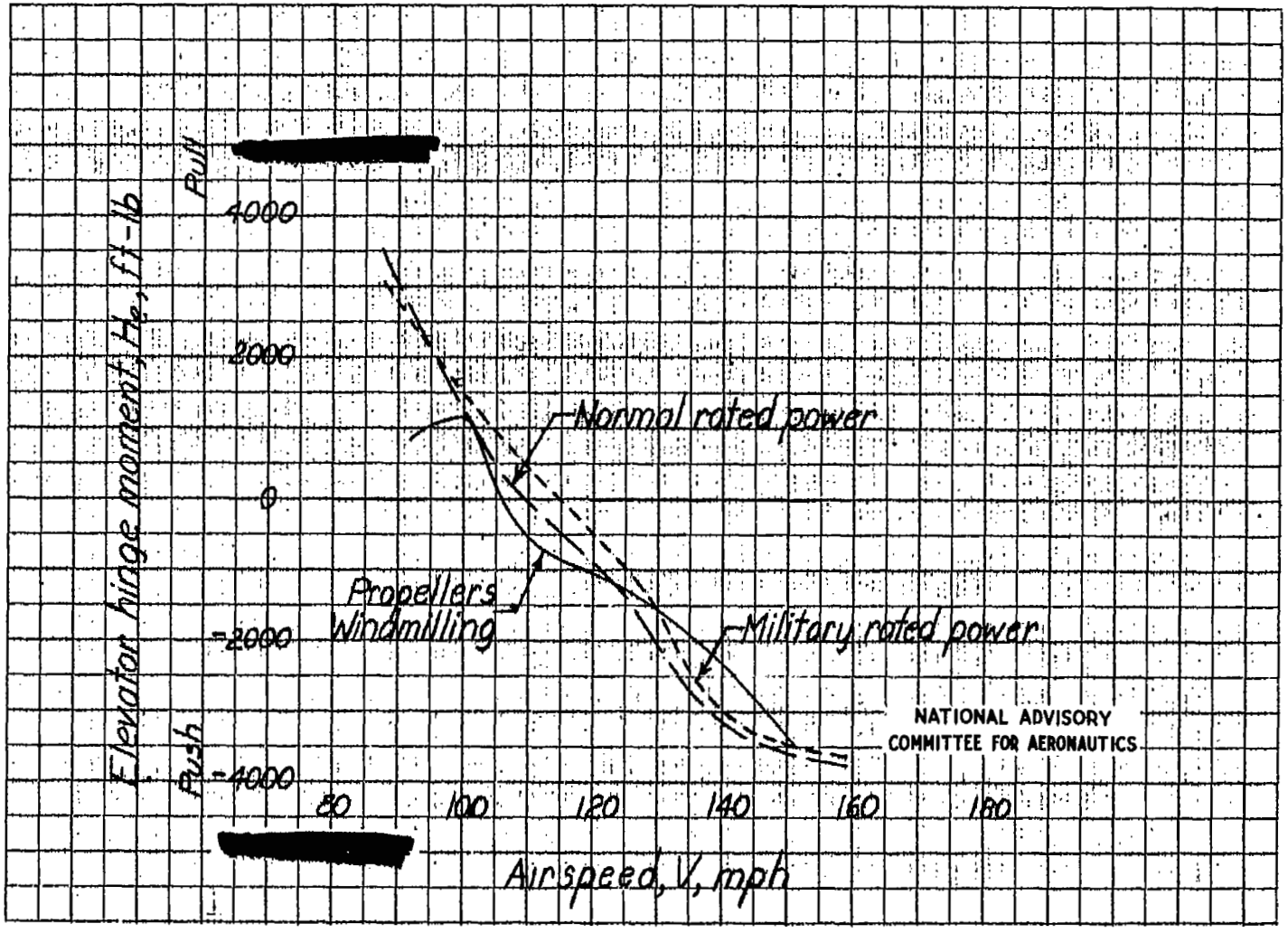


Figure 7.- Variation of elevator hinge moments with airspeed. Sea-level operation; tab neutral configuration.

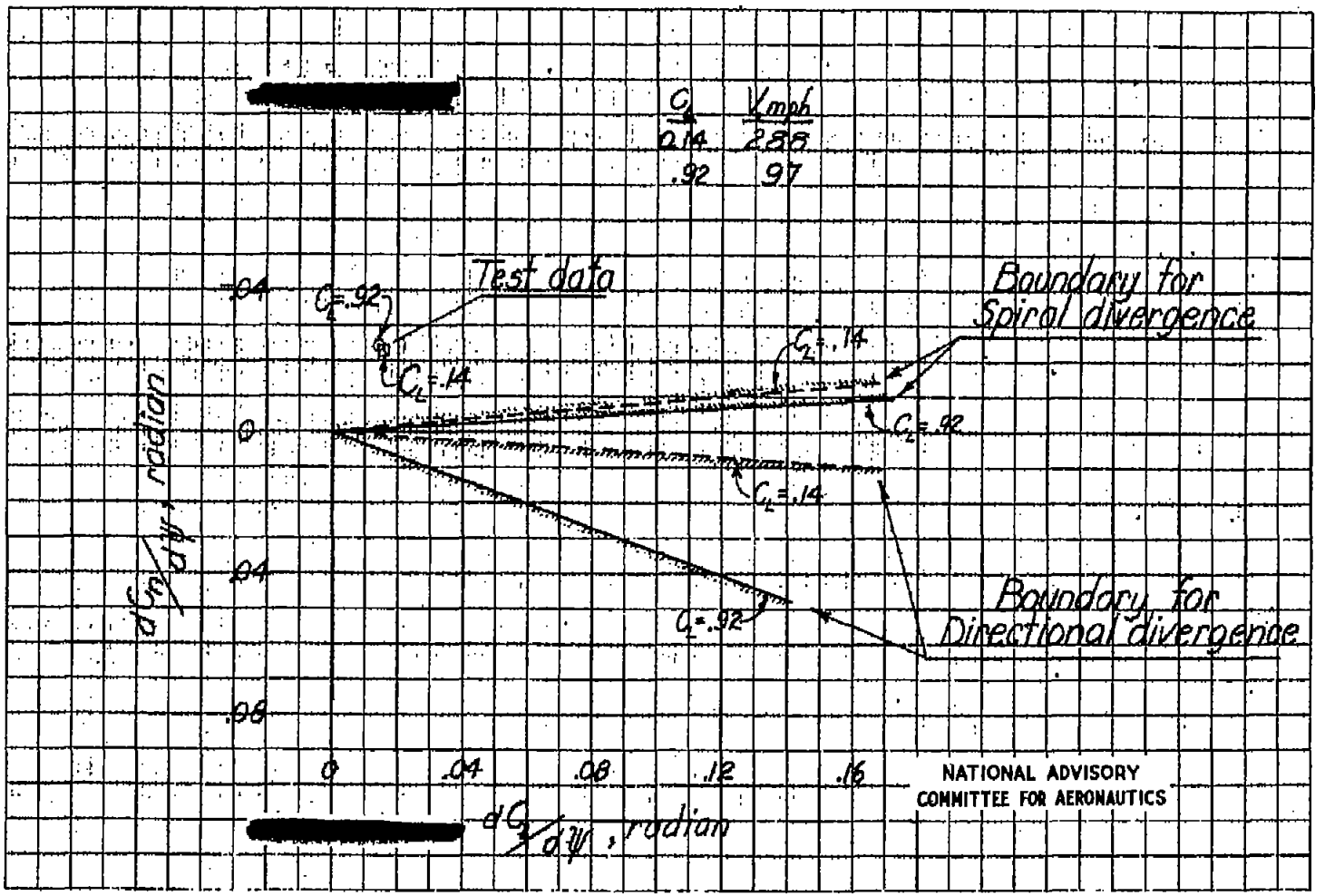
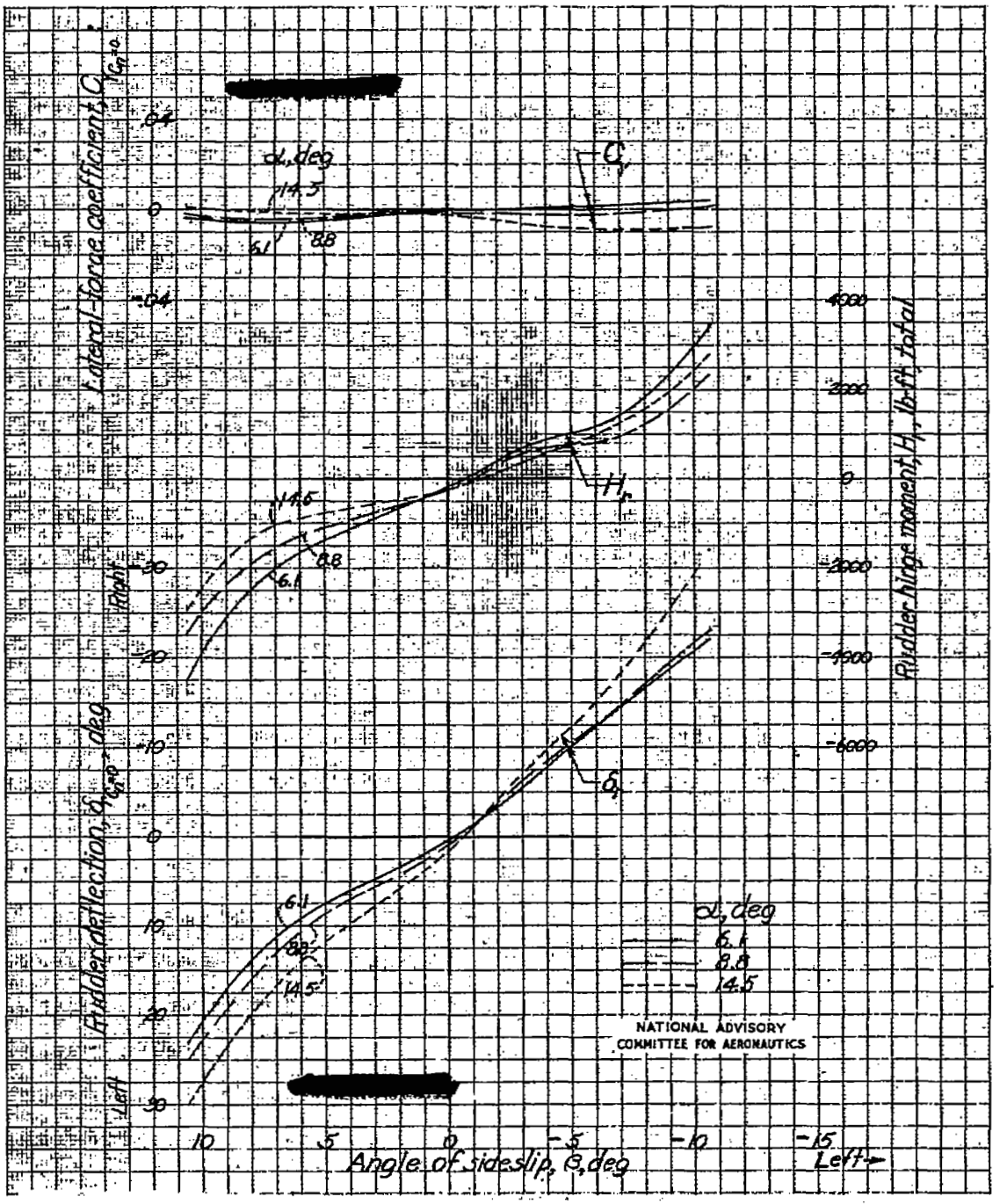
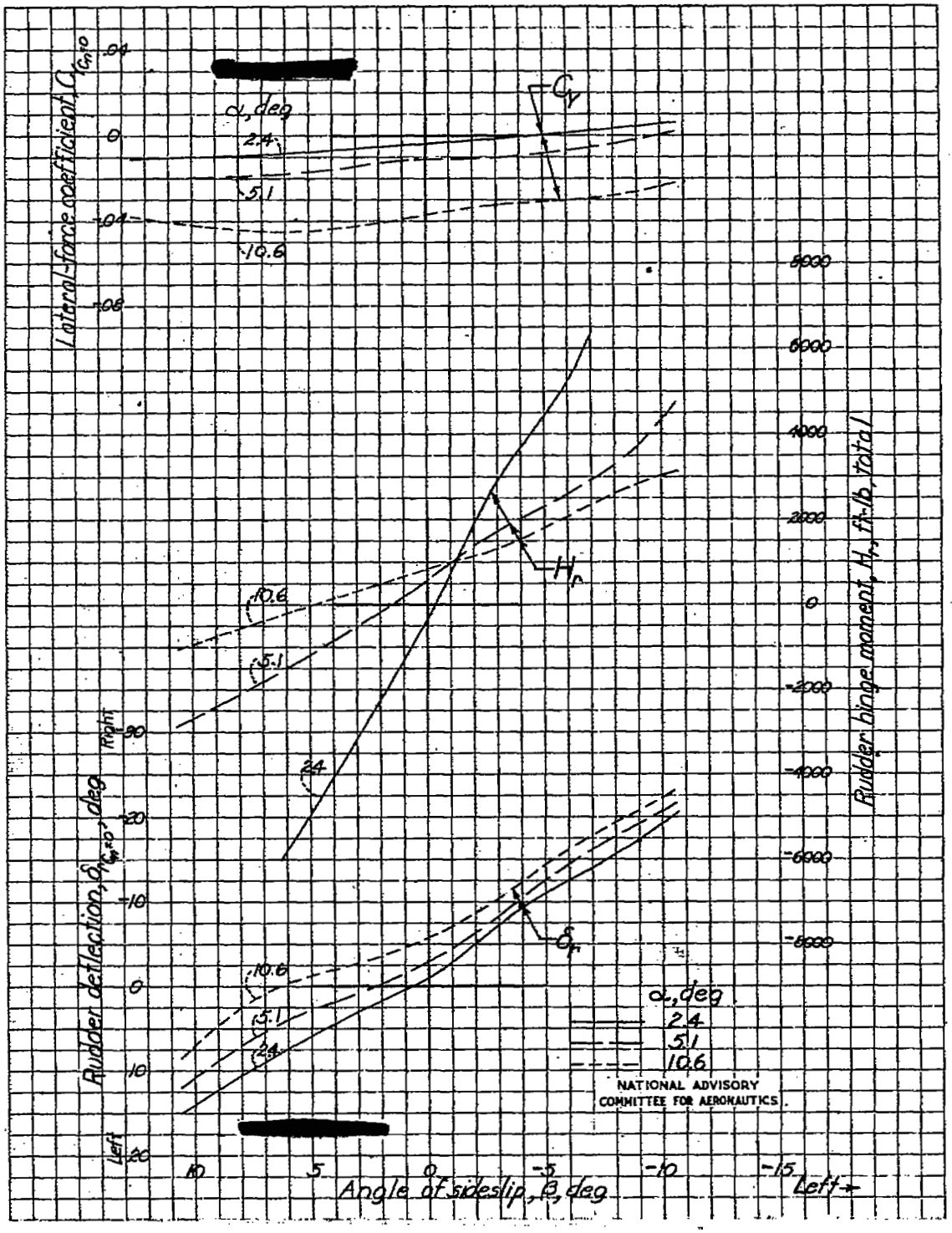


Figure 8.- The calculated spiral and directional divergence boundaries and a comparison with experimental data for lift coefficient of 0.14 and 0.92.



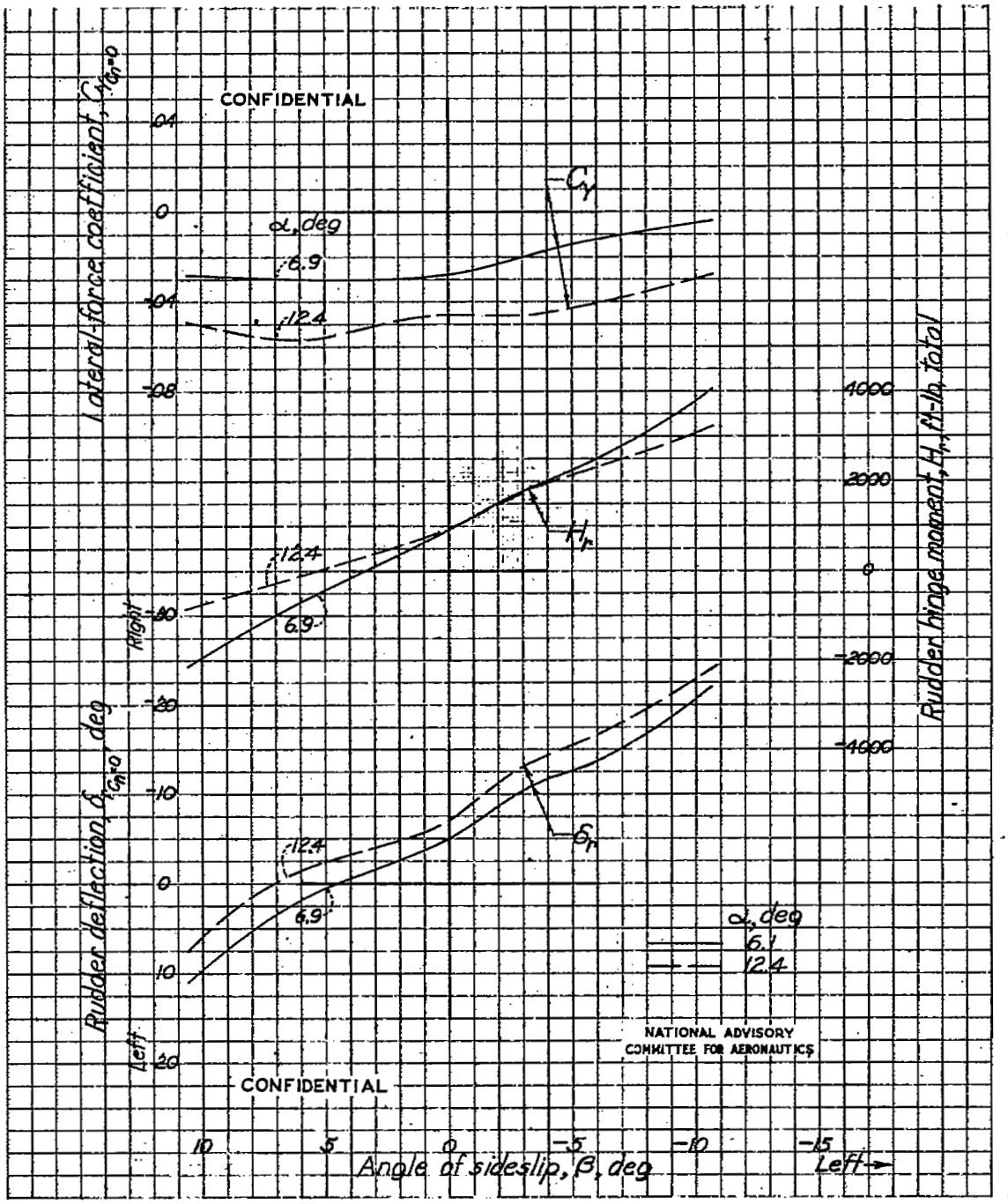
(a) Propellers Windmilling.

Figure 9.- Variations of trim rudder deflection, rudder hinge moment, and lateral force coefficient with angle of sideslip for four power conditions. $\delta_e = 0°$, $\delta_a = 0°$.



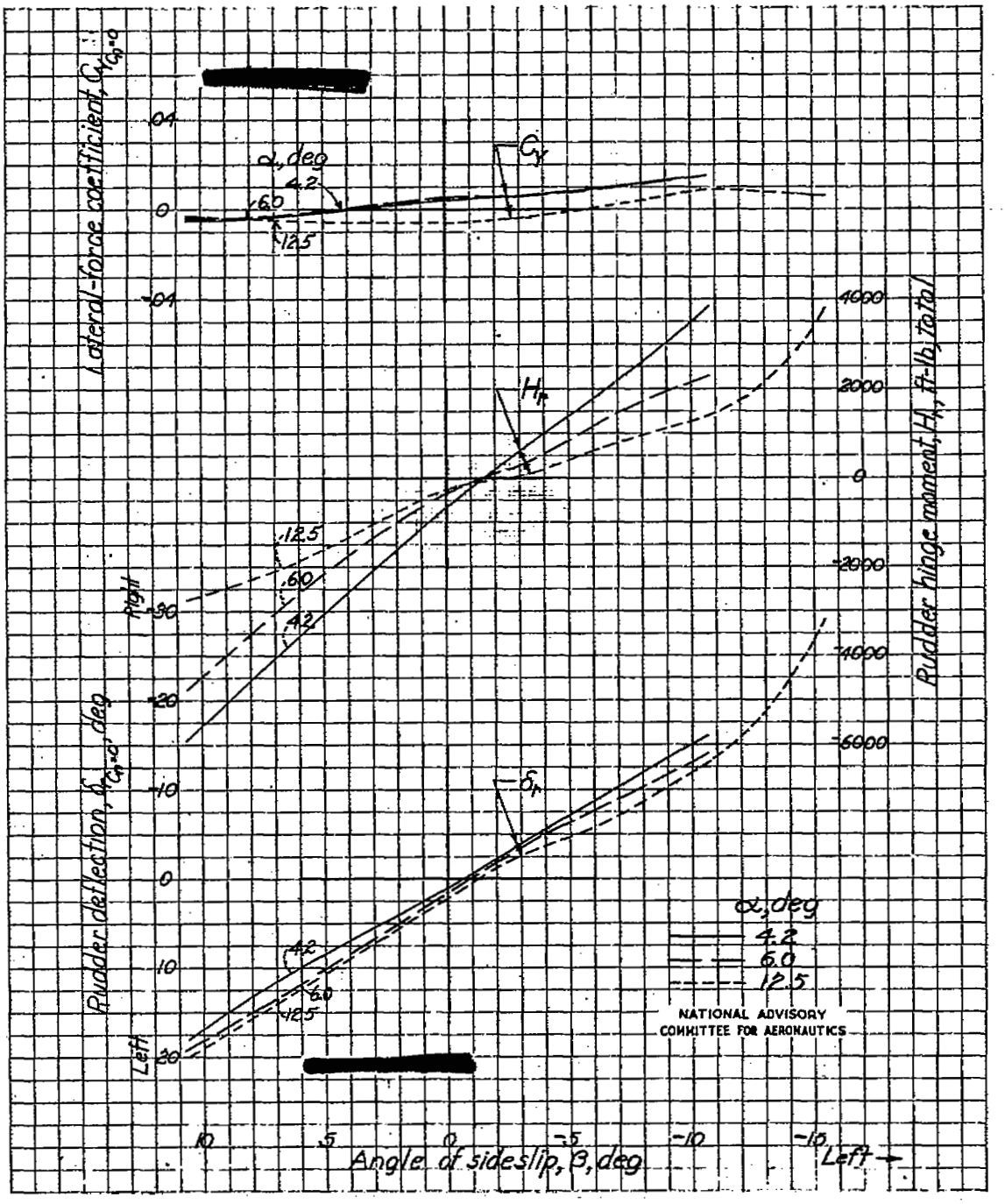
(b) Normal rated power.

Figure 9.- Continued.



(c) Military-rated power.

Figure 9.- Continued.



(d) Asymmetric power.

[Right outboard propeller windmilling; remaining engines, normal rated power.]

Figure 9.- Concluded.

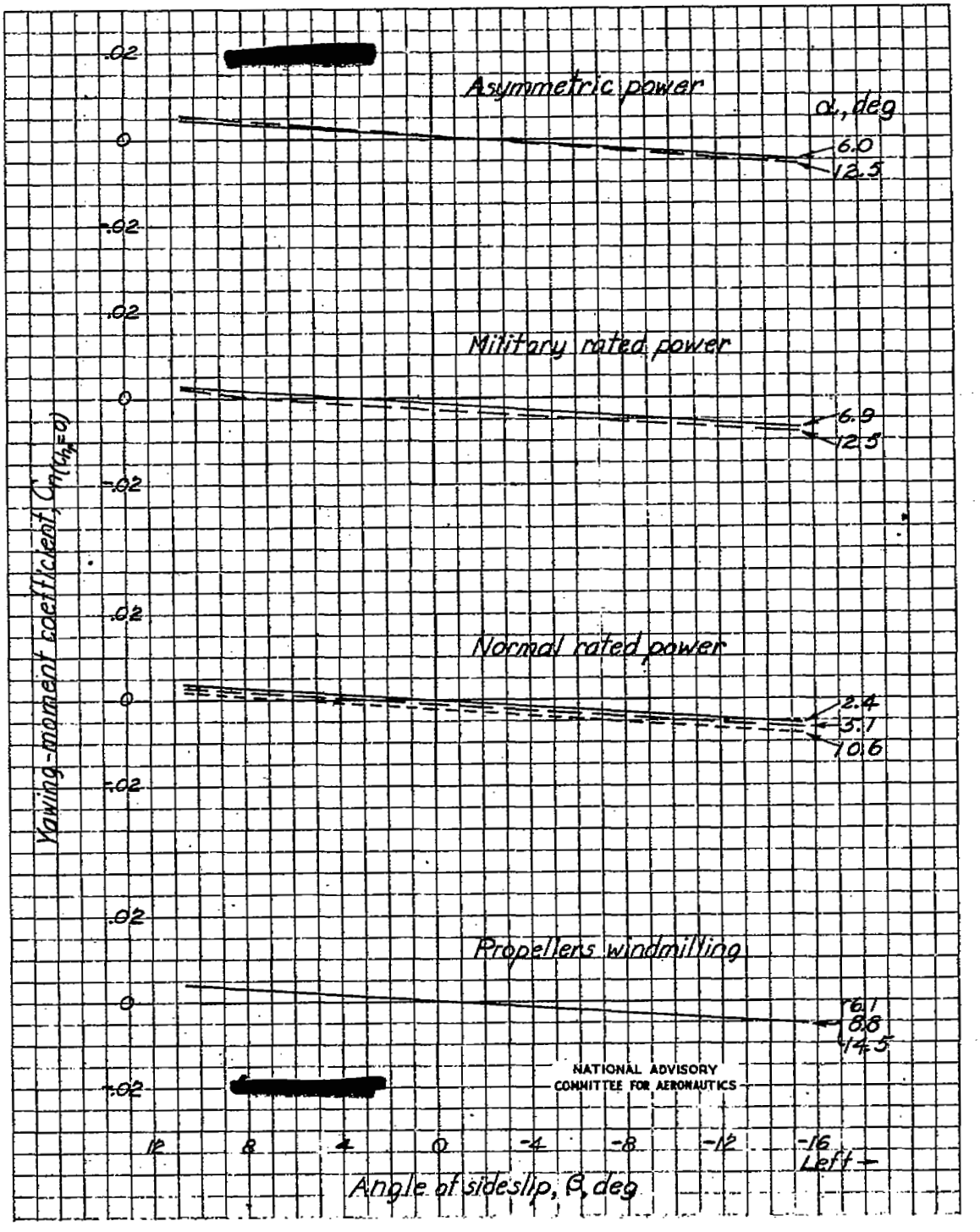


Figure 10.- Variation of the yawing-moment coefficient for $Ch_r = 0$ with angle of sideslip for four power conditions. Tab neutral configuration.

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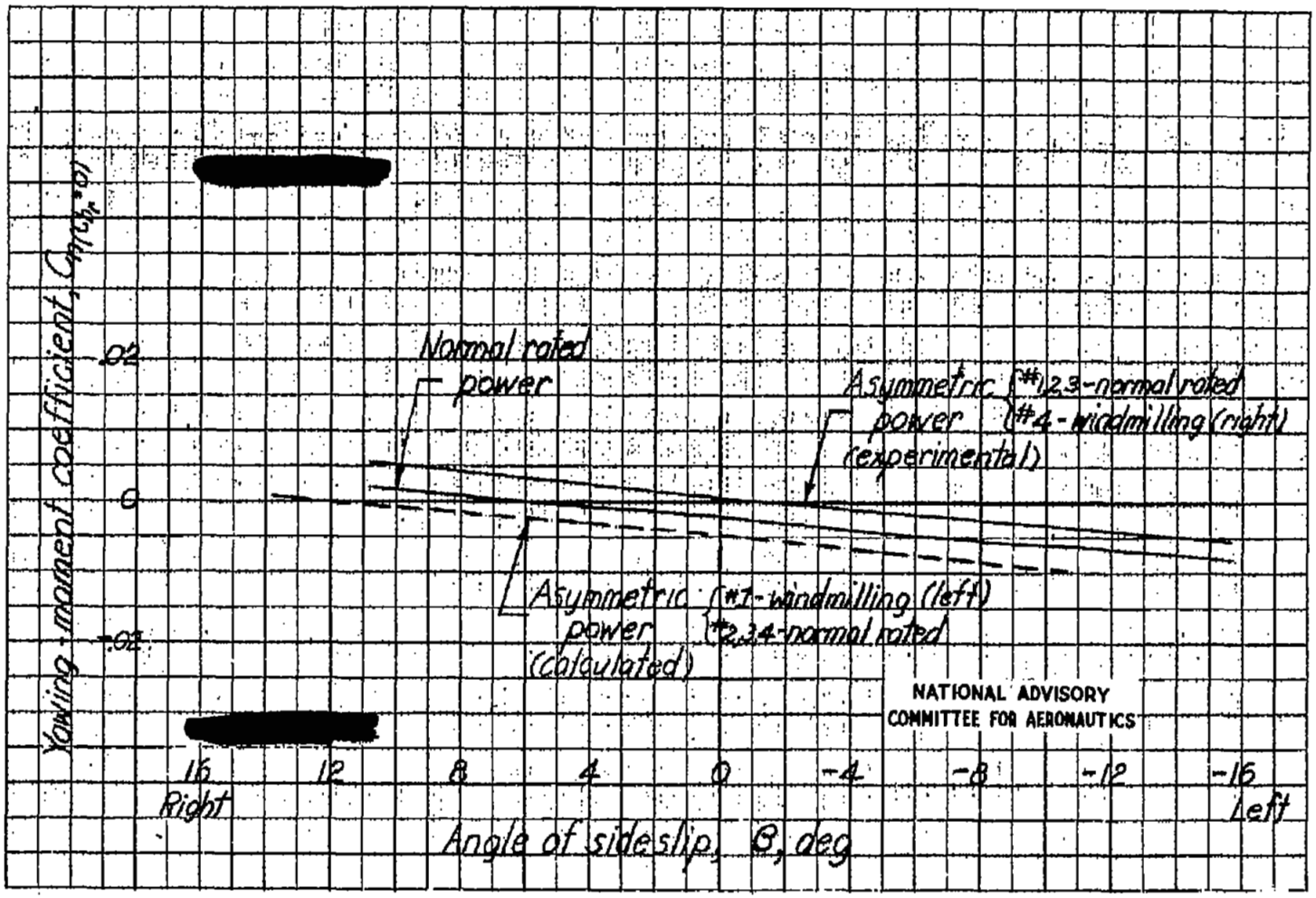

Figure 11.- A comparison between the rudder free yawing-moment coefficients of the normal rated and two asymmetric power conditions. C_L, about 1.0.

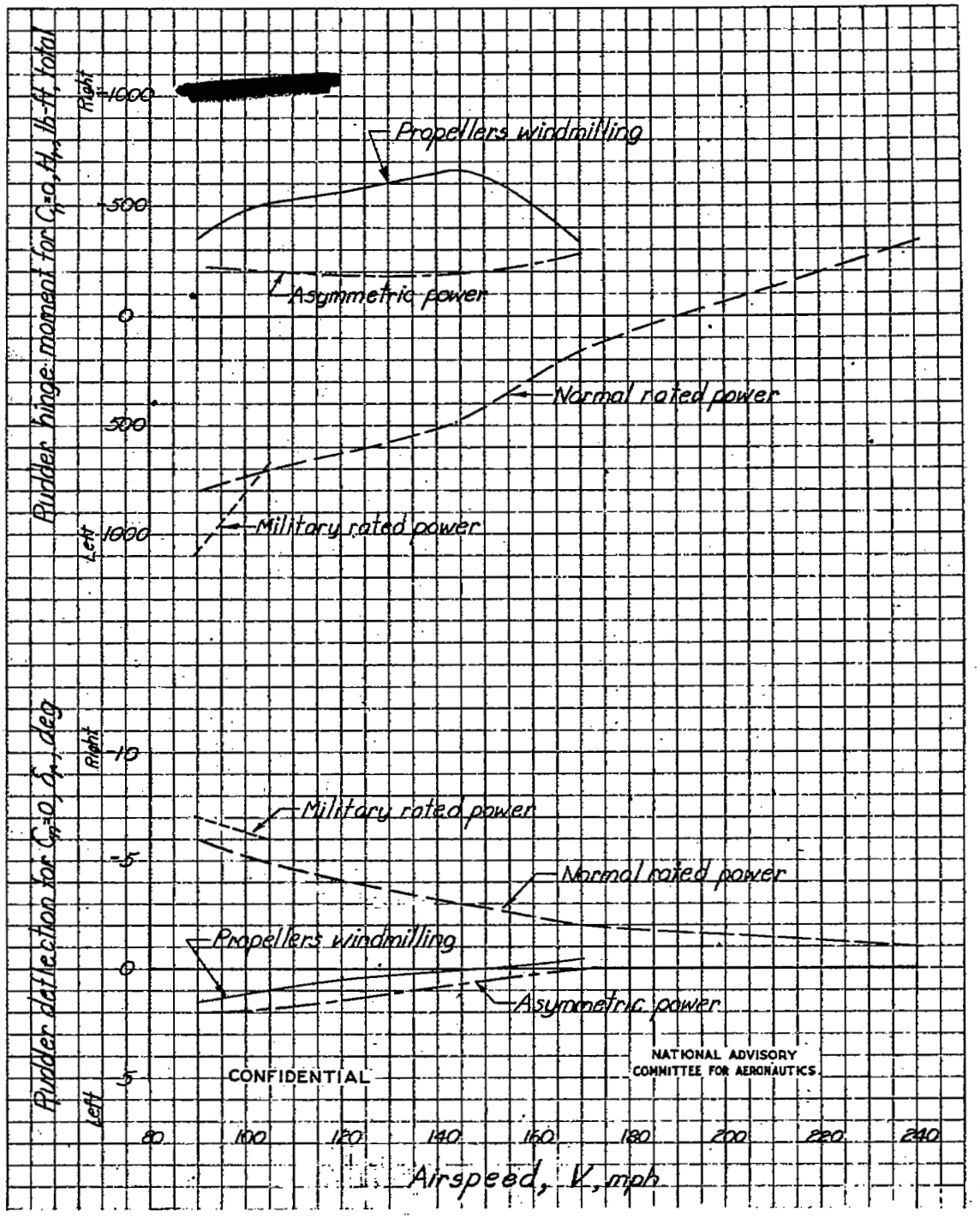

Figure 12.- Variation of trim rudder deflection and rudder hinge moment with airspeed. Sea-level operation; tab neutral configuration; $\beta = 0^{\circ}$.

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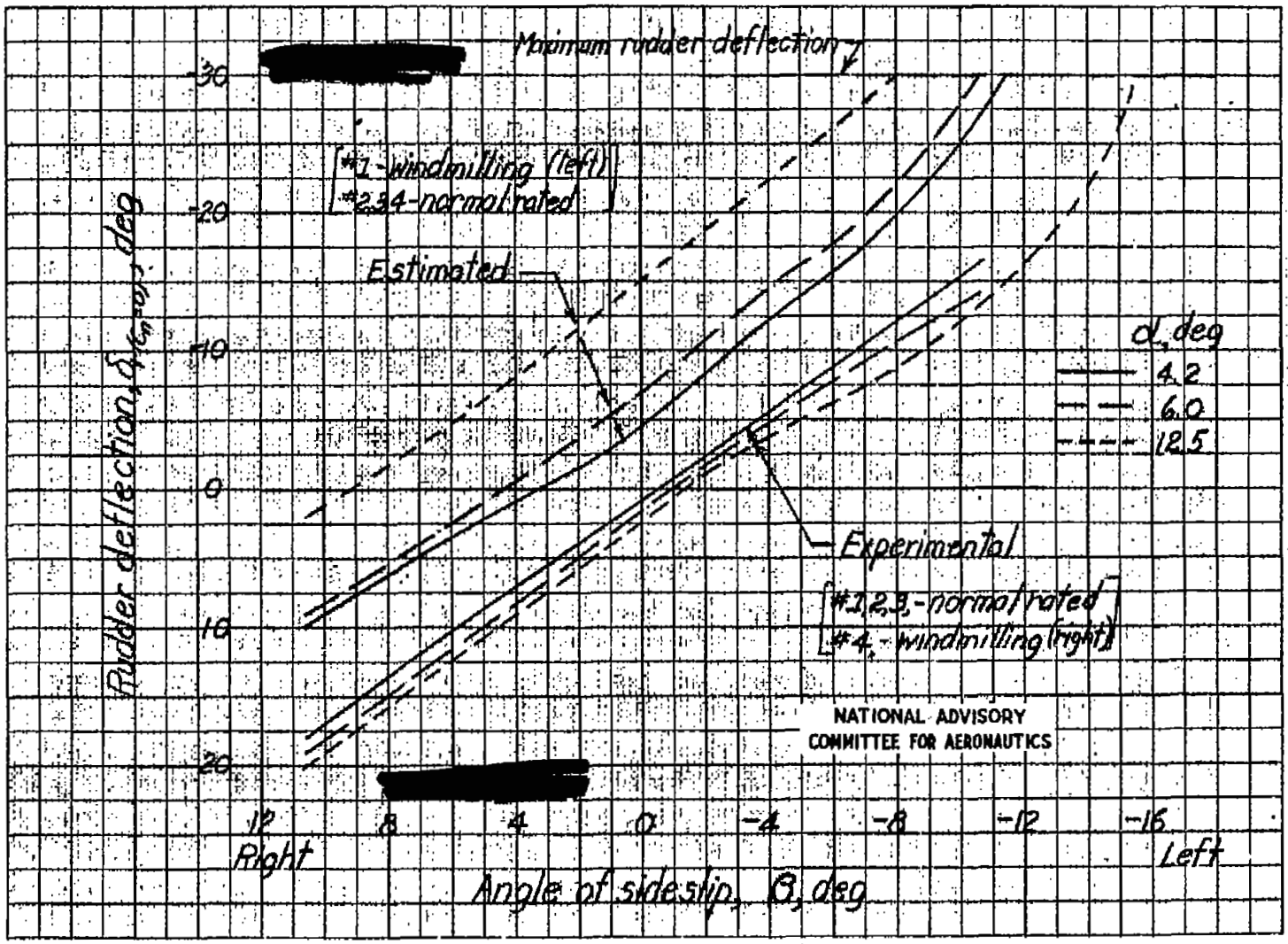

Figure 13.- A comparison of the rudder trim curves for two modes of asymmetric power with the model in sideslip.

19214

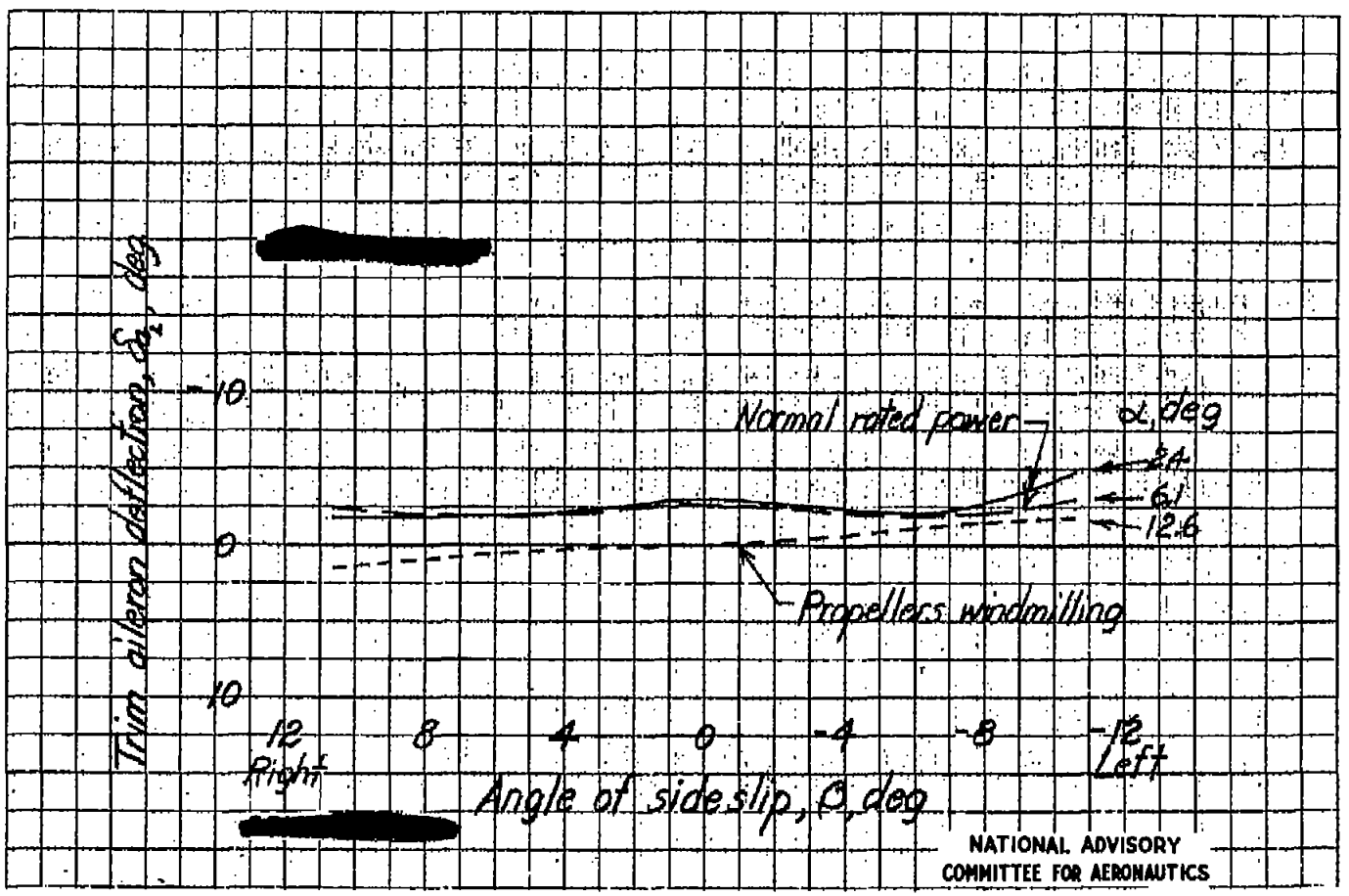

Figure 14.- Variation of trim aileron deflection with angle of sideslip. $\delta_e = 0^\circ$; rudders trimmed; tab neutral configuration; $\delta_{a_L} = 3\delta_{a_R}$.

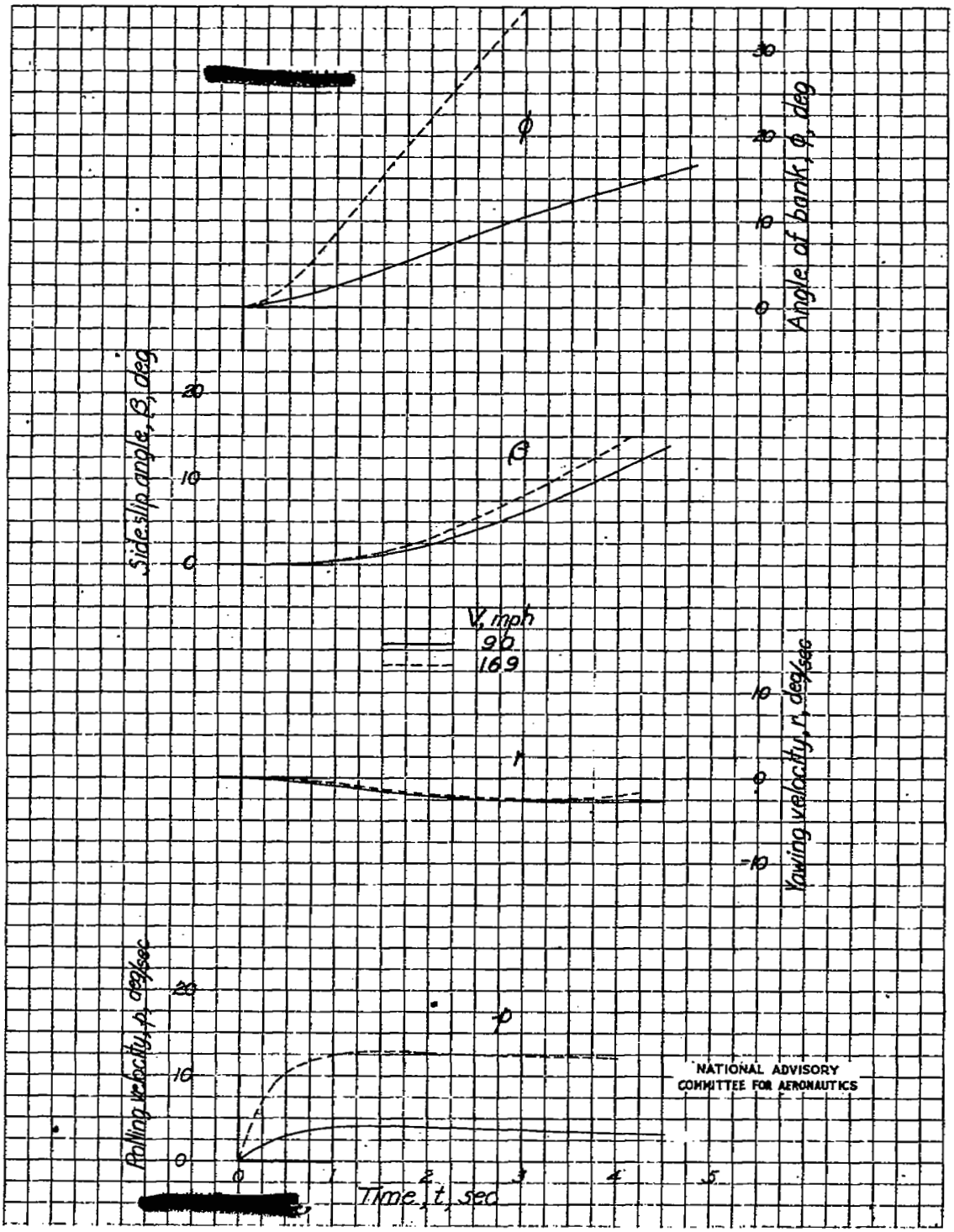

Figure 15.- Estimated time history curves for two flight speeds. Sea-level operation; Maximum aileron deflection.

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